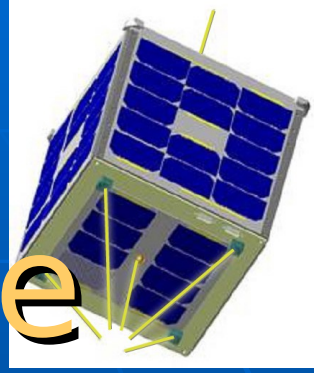
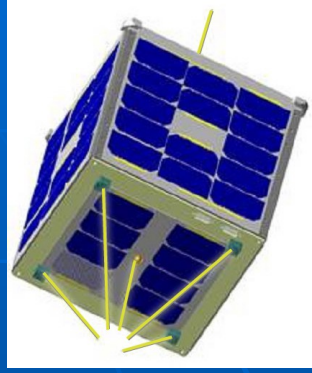
AO-51 Power Generation, Storage and Transmitter Power



2007 AMSAT Symposium
Pittsburgh, PA

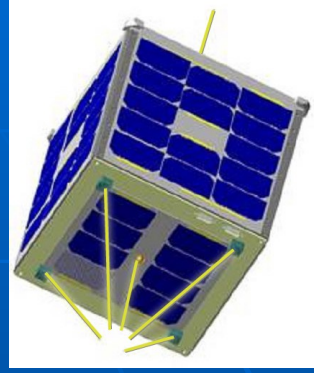
Gould Smith, WA4SXM
AO-51 Command Station

AO-51 Background



- 29 June 2004 - AO-51 (ECHO) launched
- 30 July 2004 - FM repeater opened for general use
- 2007 - Operations team schedules multiple operational modes each month
- Working extremely well 3 years after launch

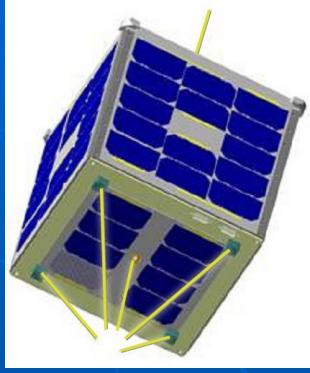
AO-51 Uplinks/Downlinks

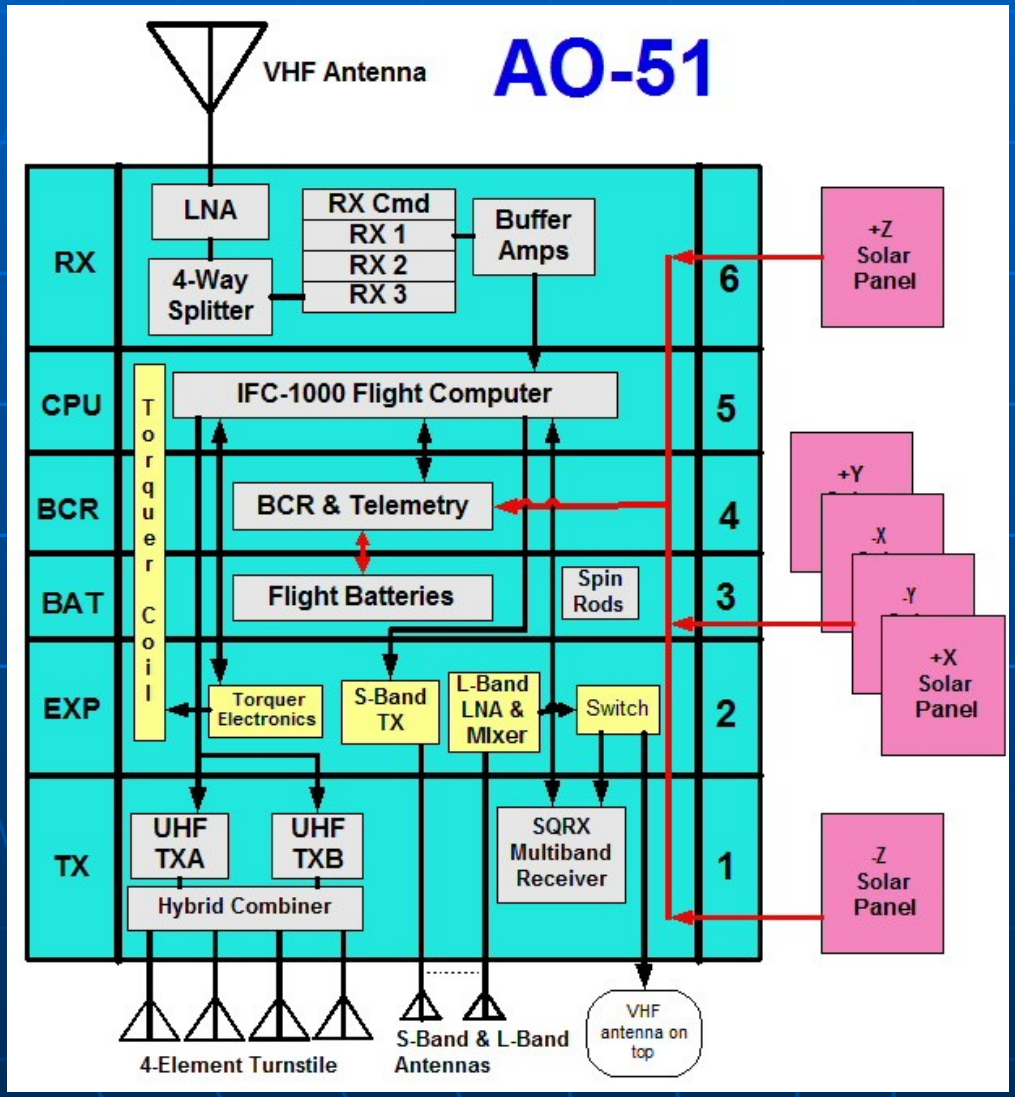


- V/U
- V/S
- L/U
- L/S
- SQRX*/U *SQRX 10 MHz – 1.3 GHz, FM & SSB
- SQRX*/S

- Generally two transmitters are active simultaneously, about 900 mW total

AO-51 Power Generation



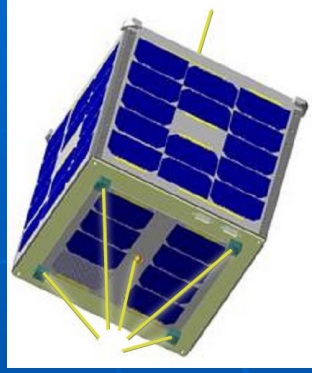


- Solar cells
- All 6 sides contain solar cells

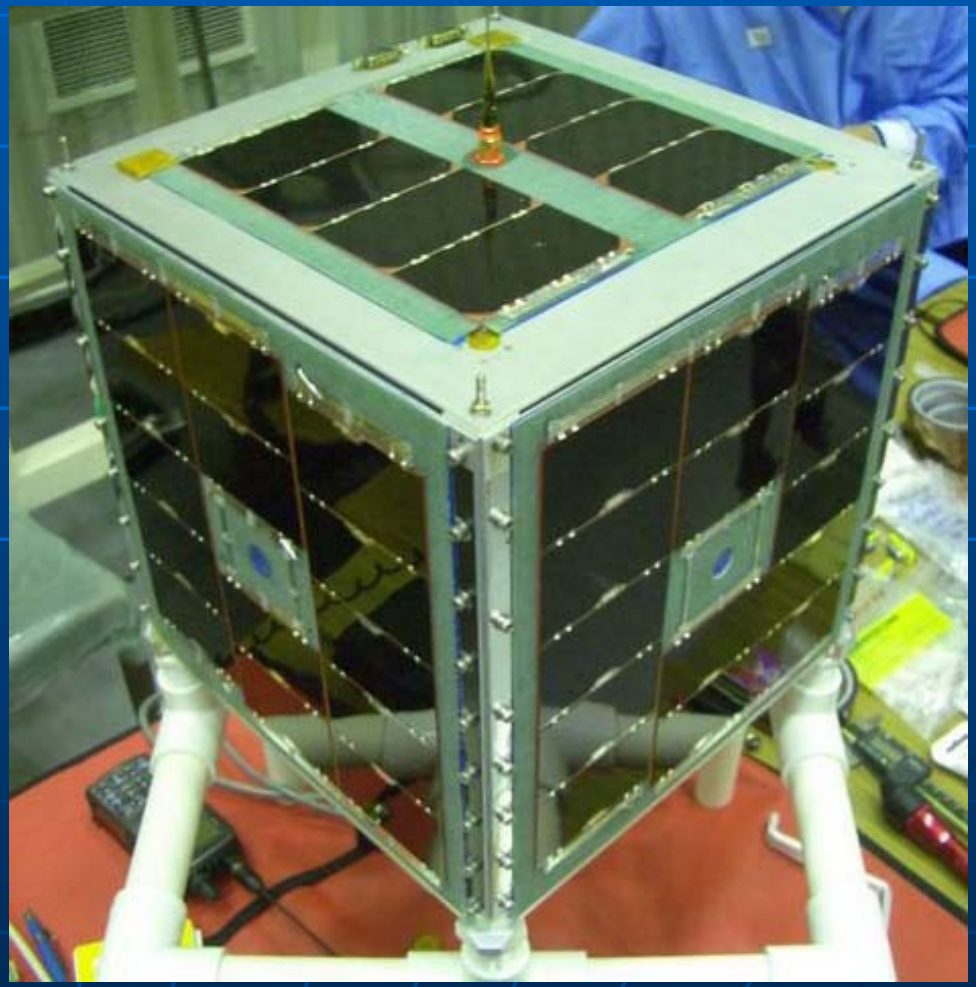
- 1/3 of the inside volume is devoted to power
- BCR
- An entire tray

- Batteries
- About 1kg mass

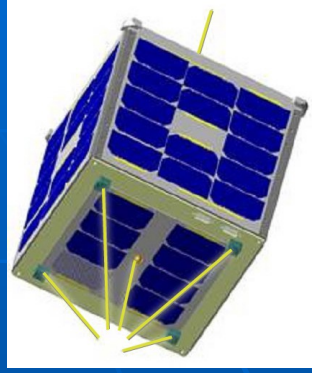
AO-51 Power Generation Solar Cells



- Triple junction GaAs cells
- Very efficient, ~27%
- Produces about 20W in full sun
- About $20,000
- 14 cells on the sides
  8 cells top/bottom



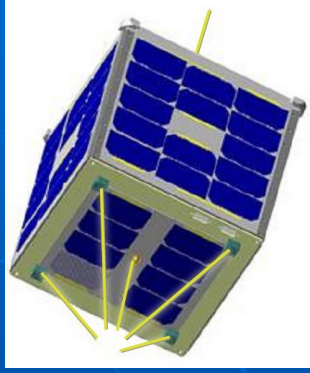
AO-51 Power Generation Batteries



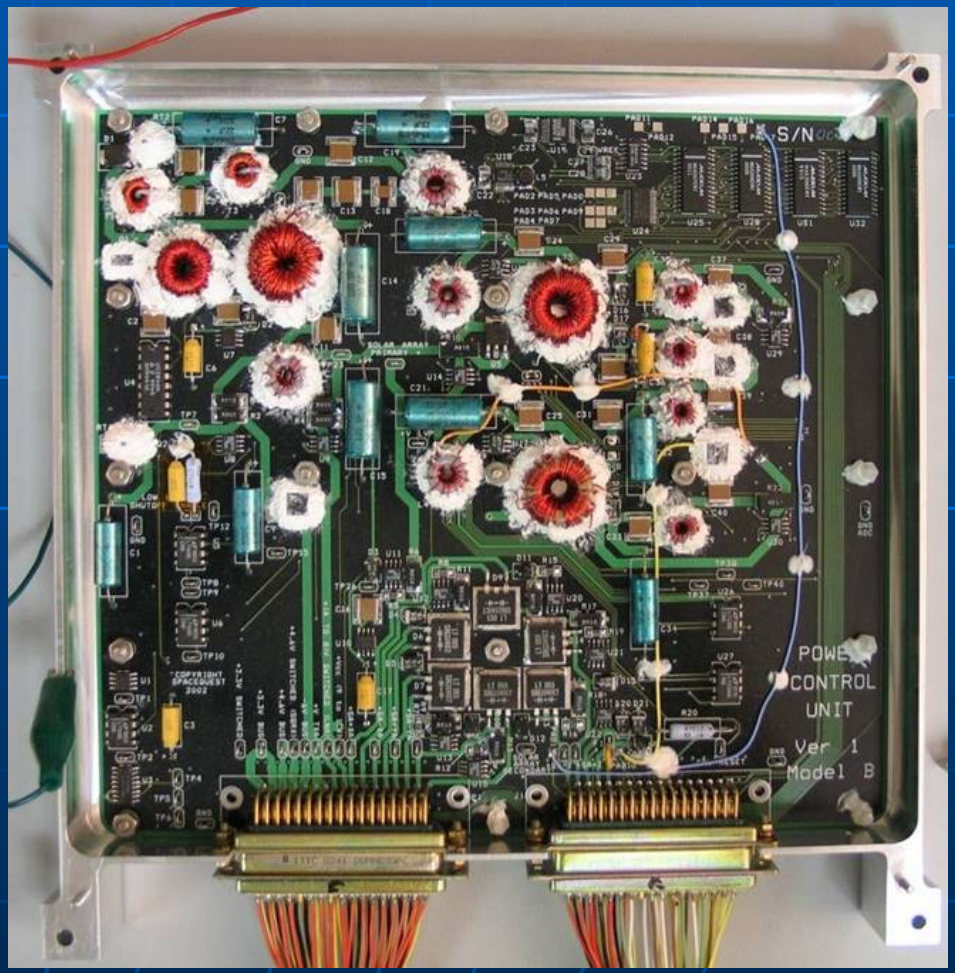
- 6 Nickel-Cadium (Ni-Cd) cells
- Nominal 1.3 V each, 7.8V total
- 4 Ah capacity
- 10 yrs or 50k cycles
- High current delivery

AO-51 Power Generation

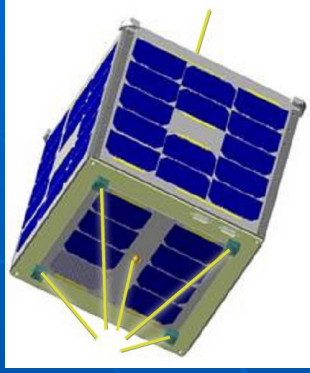
BCR (Battery Control Regulator)

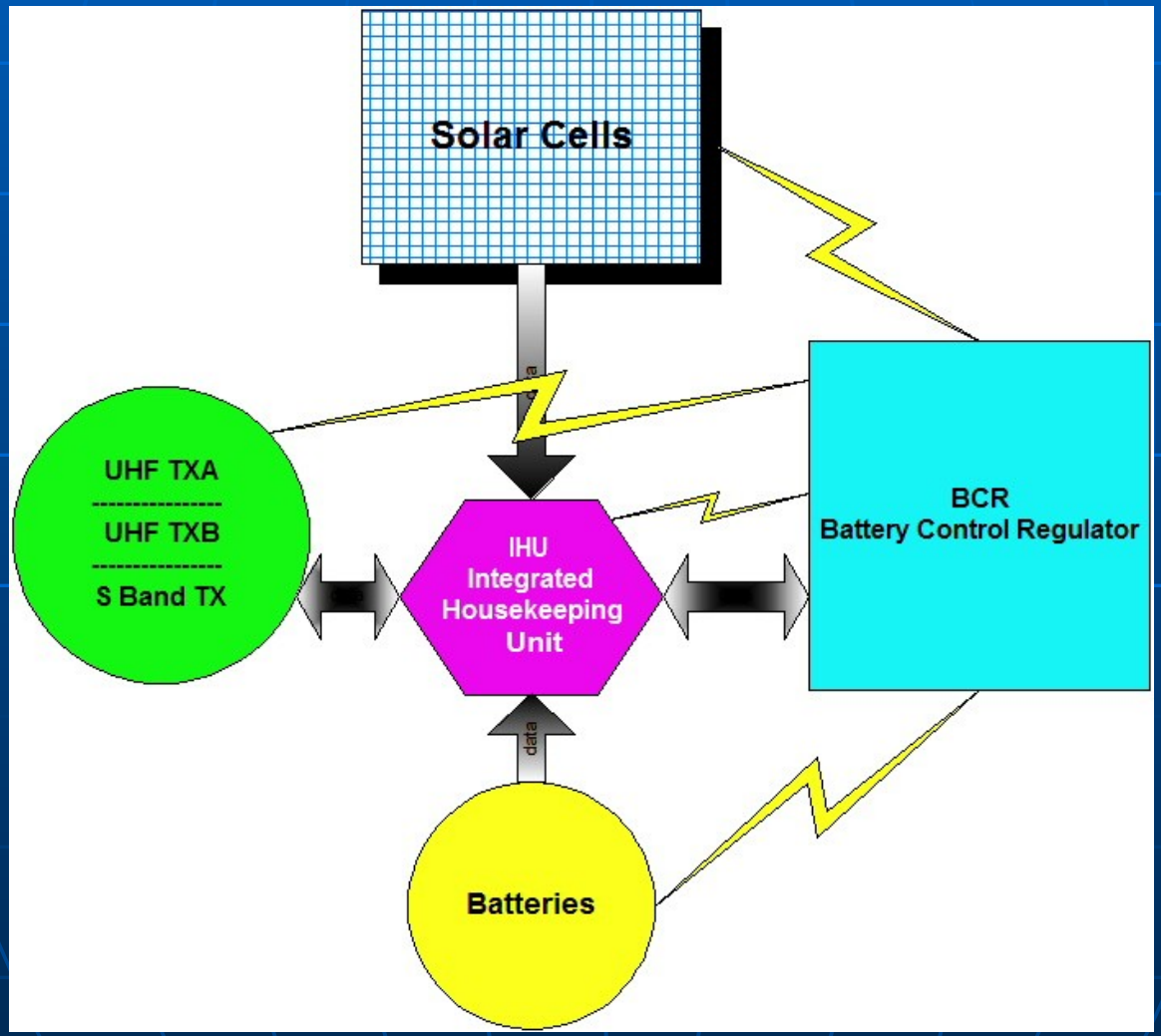


- Battery charger and voltage regulator
- Autonomous operation, no control software
- Automatic battery overcharge protection
- Arbitrates between battery and solar cells voltage source

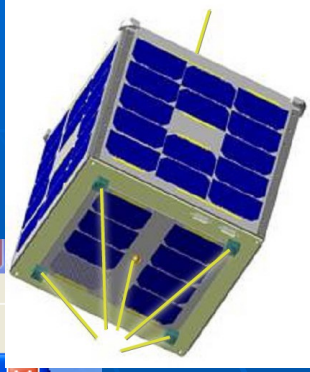


Simplified AO-51 Power System





AO-51 Power Telemetry



tlmEcho - Main Downlink View

File Setup TLM Help

Frame: 31 TLMI: 3 TLMS: 3

```
PACB-1    > TLMS-1   :C0:85 C1:44 C2:76 C3:2F C4:04 C5:01
PACB-1    > TLMD-1   :WOD:2 ATP:0 BMW:1 BMS:0 CTS:1 CTN:168 CTL:155 CTE:Thu Jun 07 01:53:20 2007
PACB-1    > LSTAT-0  :I P:0x5469 o:0 l:23619 f:27320, d:1 st:6 e:43
PECHO-12  > BBSTAT-0 :Open ABCD:
PECHO-11  > STATUS-0 :B: 36790676
PECHO-11  > PBLIST-0 :PB: Empty.
PLCTL-8   > PLCTL-8  :PLCTL Mode:2 TXA:0 TXB:0 BatTrip:0
PECHO-11  > PBLIST-0 :PB: Empty.
PACBLS-8  > PACBLS-8 :PACBLS S Meter = 0
PACB-1    > TIME-1   :PHT: uptime is 104/01:21:00.  Time is Thu May 31 14:03:27 2007
PACB-1    > TLMI-1   :<binary tlm>
PACB-1    > TLMS-1   :C0:85 C1:44 C2:76 C3:2F C4:04 C5:01
PACB-1    > TLMD-1   :WOD:2 ATP:0 BMW:1 BMS:0 CTS:1 CTN:168 CTL:155 CTE:Thu Jun 07 01:53:20 2007
PACB-1    > LSTAT-0  :I P:0x5469 o:0 l:23619 f:27320, d:1 st:6 e:94
PECHO-11  > PBLIST-0 :PB: Empty.
```

Echo Control

31 May 2007 14:03:27

PHT Time	15
Txt Bcast Ratio	6
Digipeat	ON
Batt Manage	0
WOD State	Run
EDAC Count	144

Echo Solar Power Telemetry

Solar Panels

Telemetry Time: 31 May 2007 14:03:27

	V	mA	C
+Z	15.3	302.4	26.4
+X	15.5	93.0	11.7
-Y	15.5	82.5	10.0
-X	15.4	0.0	10.5
+Y	15.5	540.7	12.2
-Z	15.5	229.1	

Total Volts: 15.15

Total mA: 974.0

To BCR System

Echo TX & RX Telemetry

Telemetry Time: 31 May 2007 14:03:27

UHF TX

	TXA	TXB
PWR (watts):	0.37	0.52
Enable:	ON	ON
PTT:	ON	ON
CTCSS:	OFF	OFF
TX I Amps:	0.90	

S Band TX

Exciter:	OFF
Power Amp:	OFF
OSC Temp:	9.7
PA Temp:	10.5

SQRX

RSSI:	4095
Spkr:	4095
Power:	OFF
Antenna:	L/S

VHF RX

Power:	ON
RX1 Channel:	PRI
RX2 Channel:	PRI
RX3 Channel:	PRI

Echo Battery & BCR Telemetry

Telemetry Time: 31 May 2007 14:03:27

	1	2	3	4	5	6
	1.43	1.44	1.42	1.43	1.49	1.40
Volts:	1.43	2.87	4.29	5.72	7.21	8.61
Temp C:	10.0	10.2				

BATTERIES

Bat V 8.61

Bat mA 544.3

BCR/Power System

Main V reg Temp 23.5

TX V reg Temp 16.8

Solar V 15.15

Solar mA 974.0

from Solar System

3.3 V 3.34

3.3 mA 70.5

4.6 V 4.61

4.6 mA 104.4

Low Volt mA 53.0

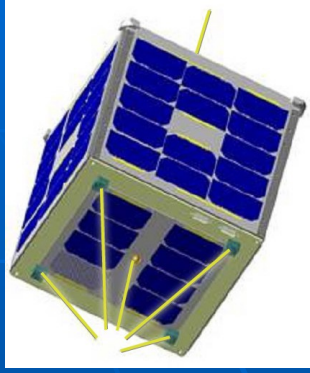
+4V #1 4.03 V

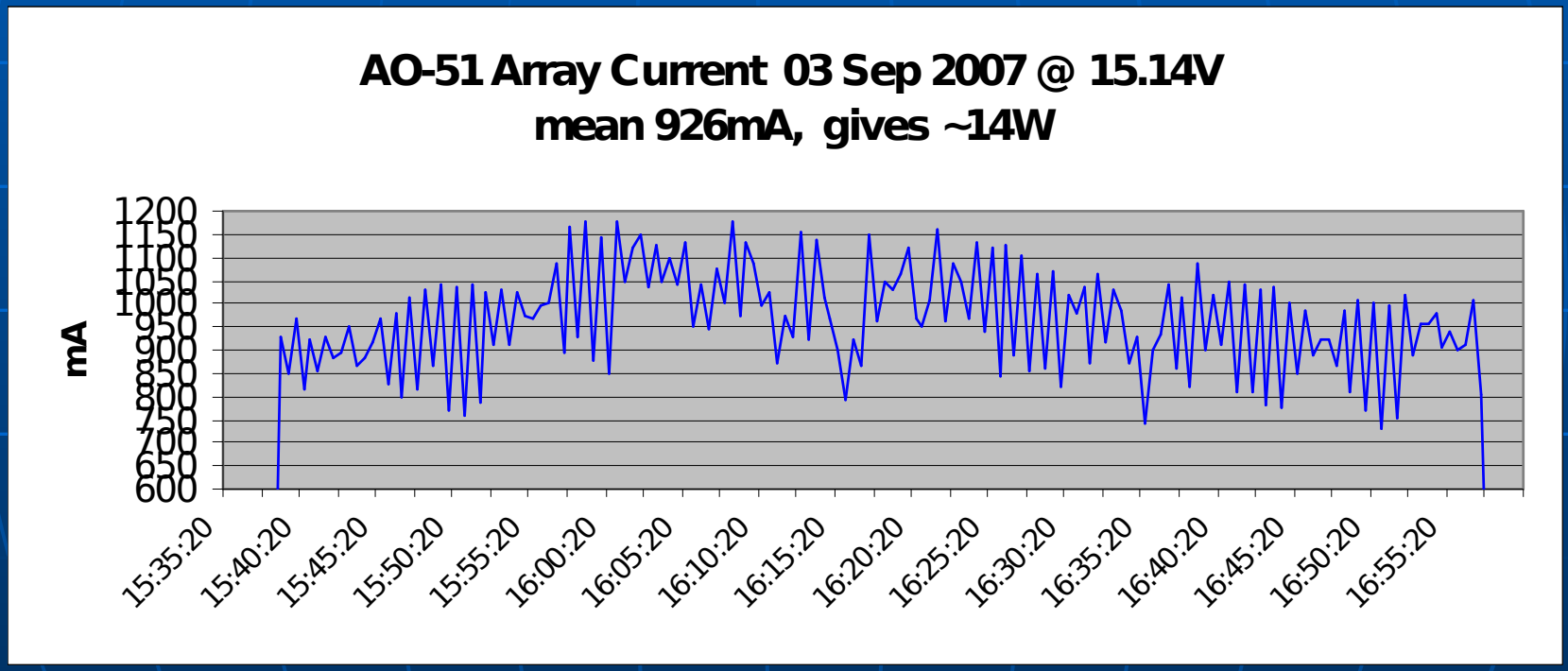
+4V #2 4.03 V

Azimuth	Elevation	MA	Height	Range	L	SSP	B	Orbit	Squint	Aos	Los	MaxE
154.2	44.2	197.2	753	1026	279	30		15330	--	*****	14:01	59

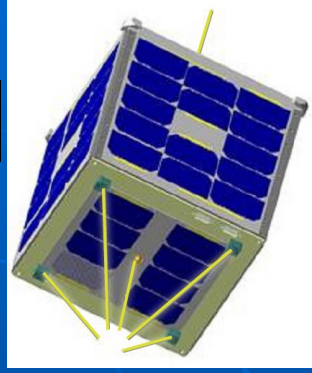
start | SatPC32 [Standard] | SDX 157/45 | Groundstation Control | 5 Tlmecho | Norton | 9:55 AM

AO-51 Solar Cell Power



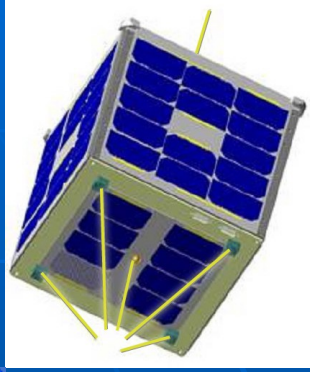


Historical AO-51 Solar Cel Data



Collect and graph 2004 – 2007 solar cell data for Sept and Jan/Feb

AO-51 Polar Orbit and Eclipse



SatPC32-Ya [Standard A:AO-51] [Registered to Gould Smith, WA4SXM]

File Tracking Satellites CAT Rotor Mode Setup Programs Accy ?

QTH: -84.0 / 35.6 Eclipsed

R+ C+ A- V- T0 U CW- AL

M+ Z1 G+ S+ D+ W2 2D

Downlink 0 Corr.(+/-) 0 Uplink

435163.471 145856.825

9.471 -3.175

20 100 500 1k 5k

D-Corr: Upl/Dwnl

07.03.2007

01:15:13 U

E:WO-52 Aos:02:42 maxE:28

F:SO-50 Aos:06:02 maxE:15

G:156 Aos:13:21 maxE:07

I:AO-27 Aos:08:36 maxE:22

H:AO-16 Aos:10:22 maxE:23

C:FO-29 Aos:07:42 maxE:14

D:AO-07 Aos:01:39 maxE:53

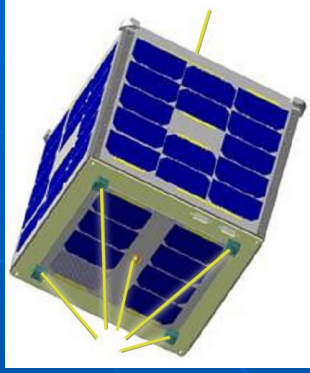
B:SO-32 Aos:01:48 maxE:74

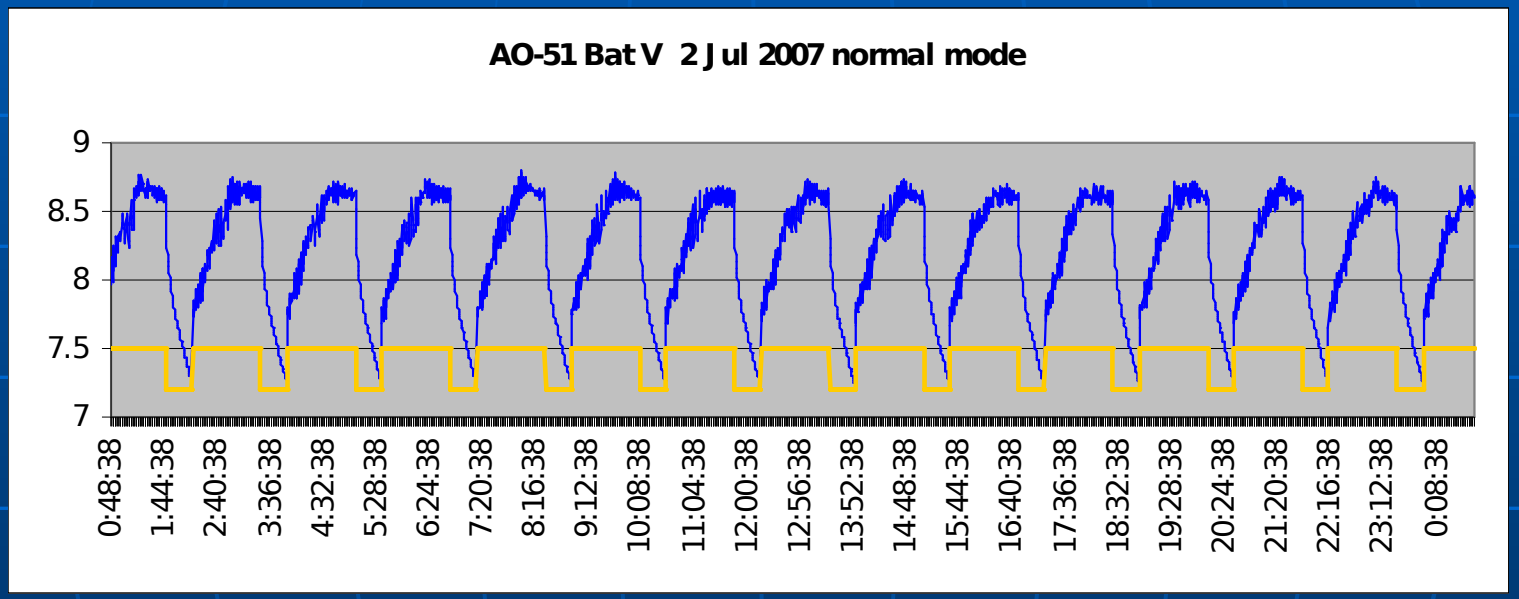
Azimuth	Elevation	MA	Height	Range	L SSP	B	Orbit	Squint	Aos	Los	MaxE
153.3	10.3	175.6	783	2313	285	19	14099	--	*****	01:28	60

A B C D E F

G H I J K L

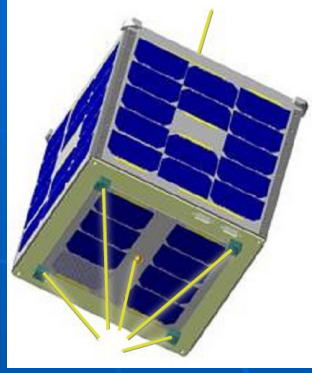
Standard AO-51 Eclipse Cycle

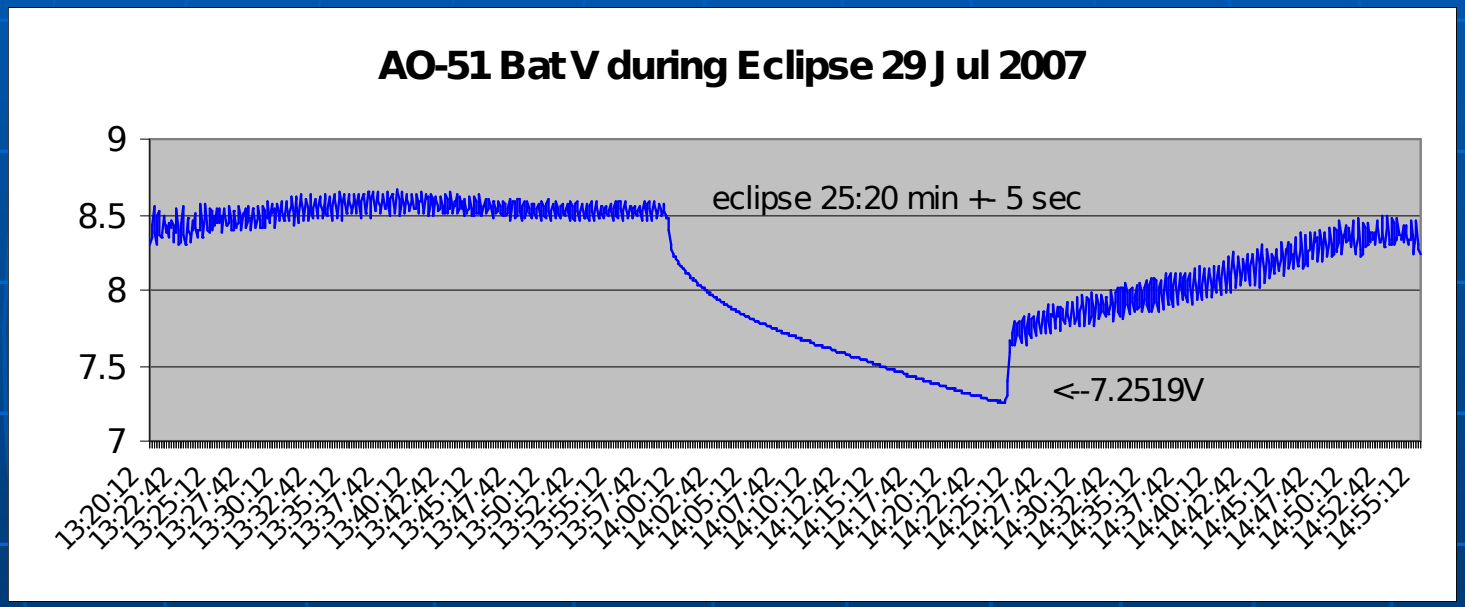




- Basic 24 hour, 14 orbit Battery Voltage cycle
- Yellow line follows the satellite in sunlight and eclipse
- 30 second WOD (Whole Orbit Data)

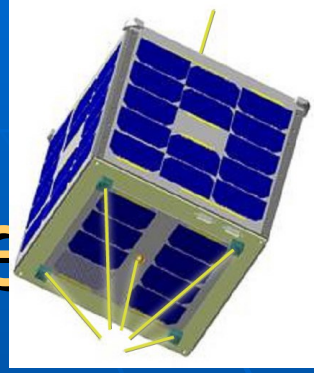
Single Orbit Eclipse

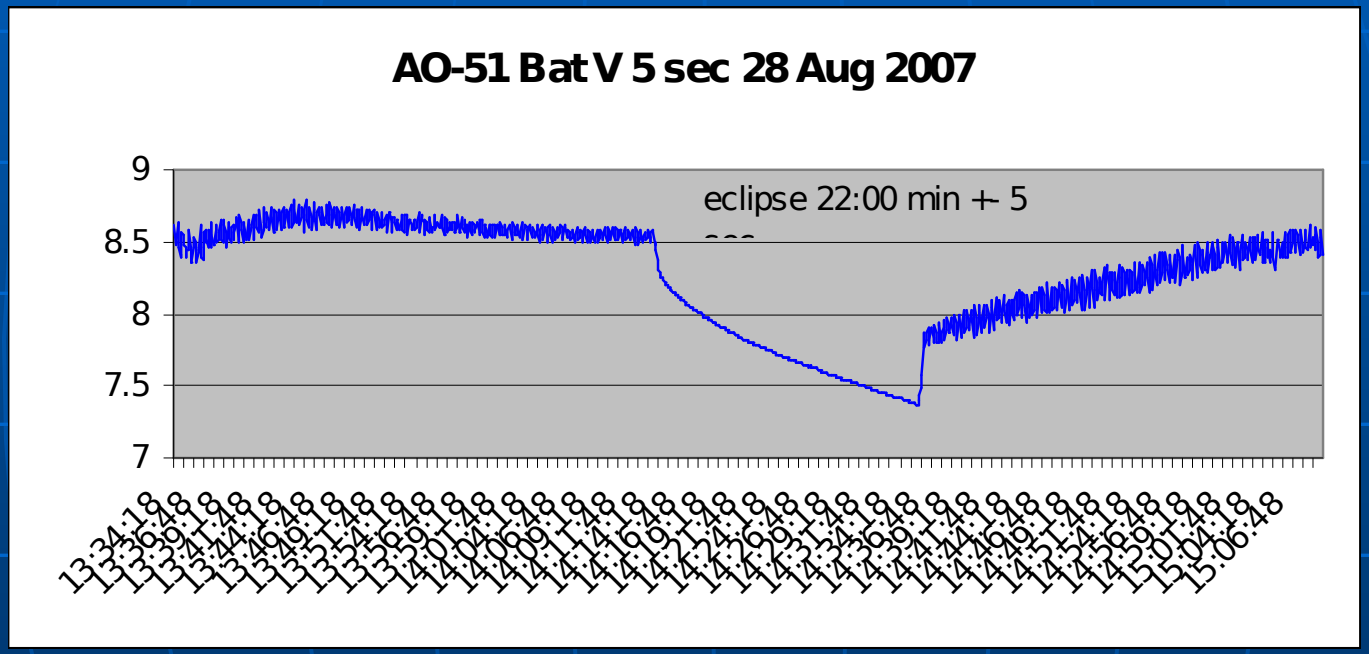




- AO-51 goes into eclipse each orbit, for 18-33 min
- The satellite is powered solely by the batteries
- The minimum battery voltage during eclipse is determined by the TX power levels and the length of the eclipse

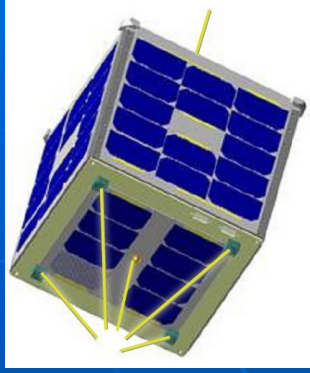
AO-51
Minimum Battery Voltage





- The shorter the eclipse period, the more power available for TXs
- NiCd Battery “memory effect” ?
- There are low battery set points that will shut down transmitters when these levels are reached

AO-51 Eclipse Periods



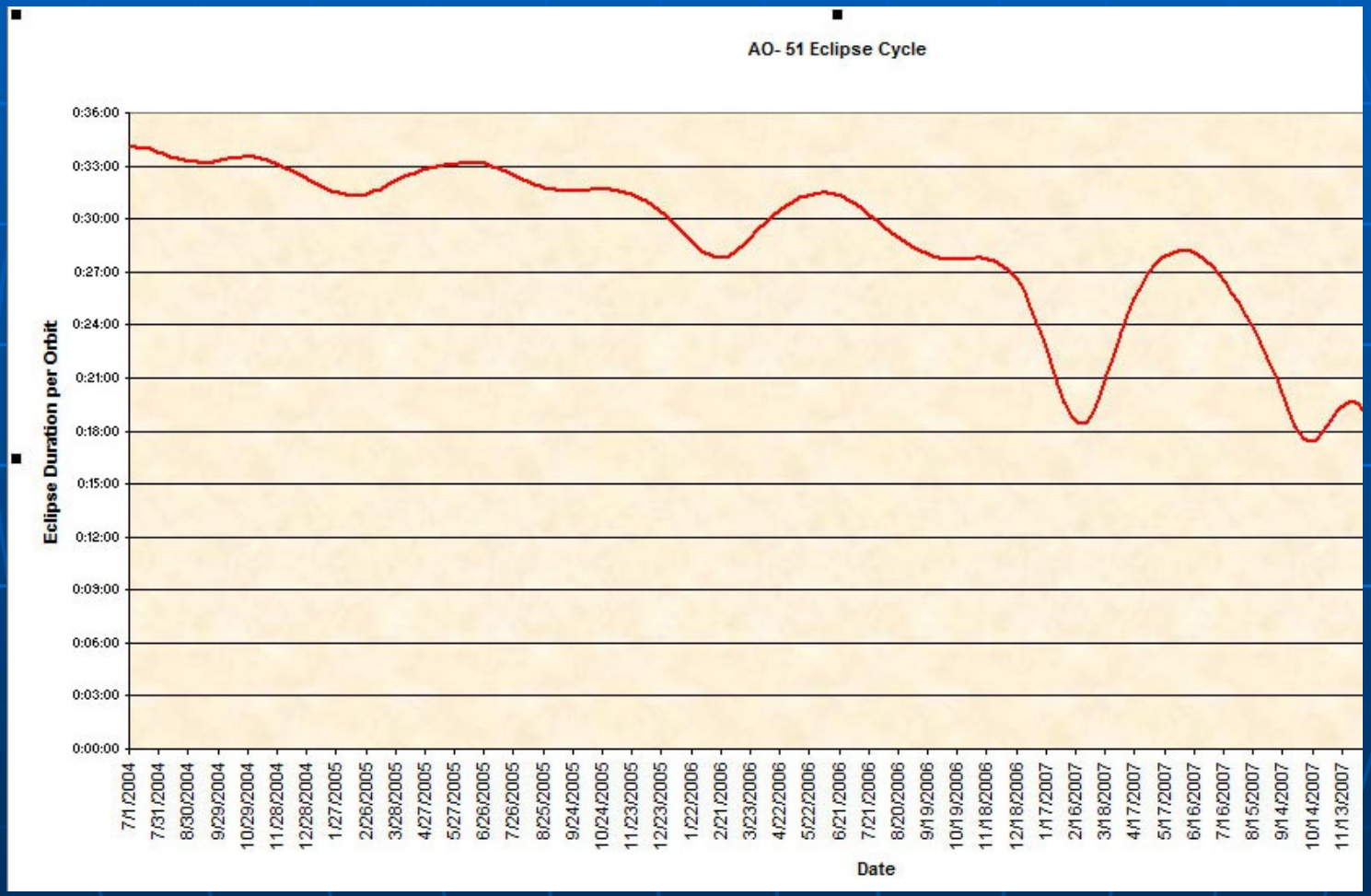
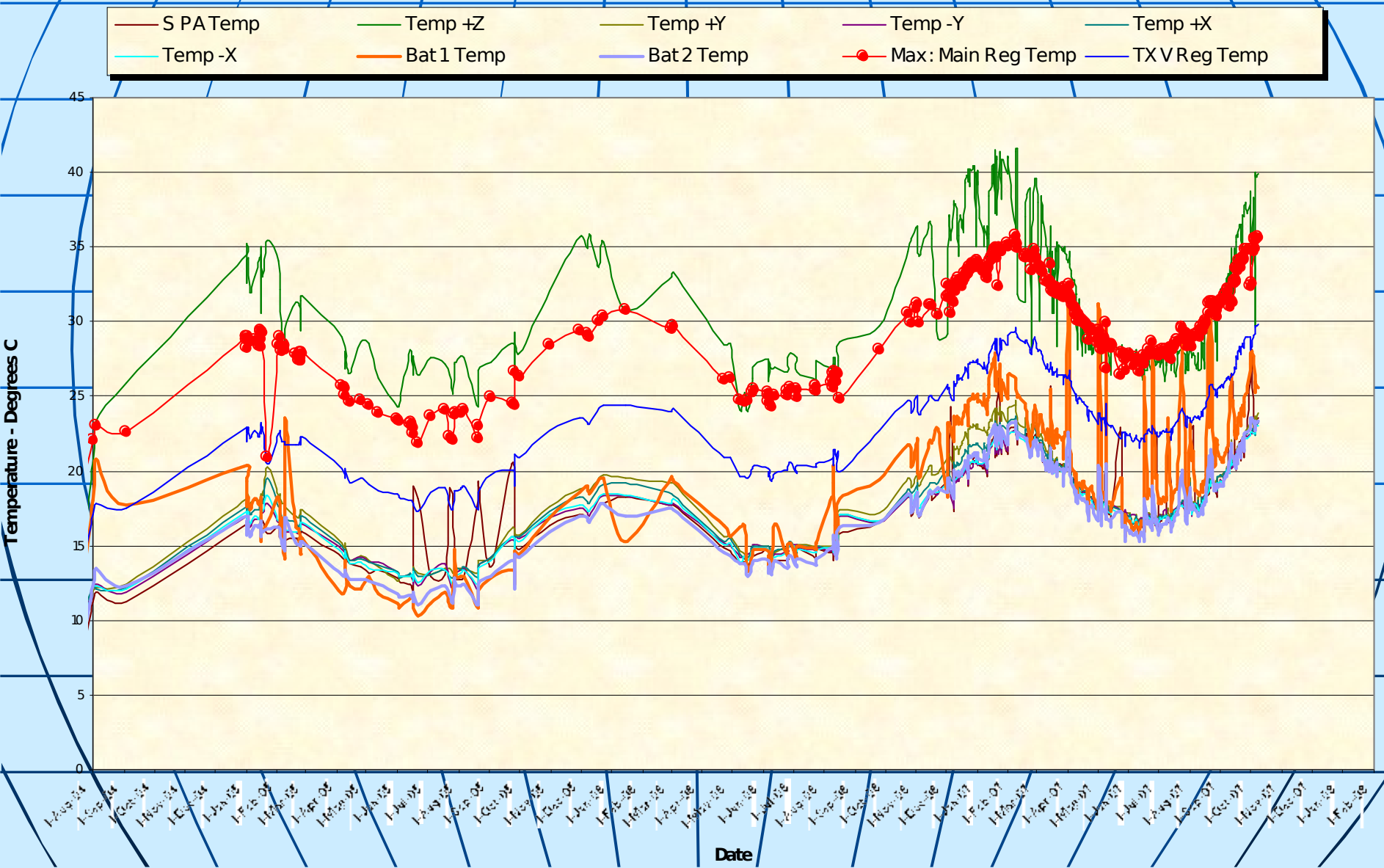


Chart by Colin, VK5HI using W4SM Eclipse Prediction software

AO-51 Maxima Temps



NiCd Batteries

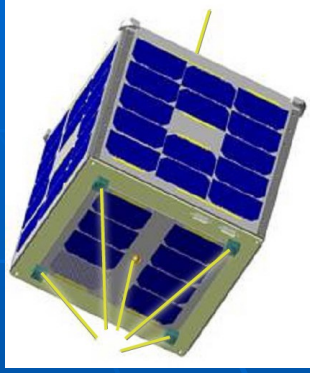
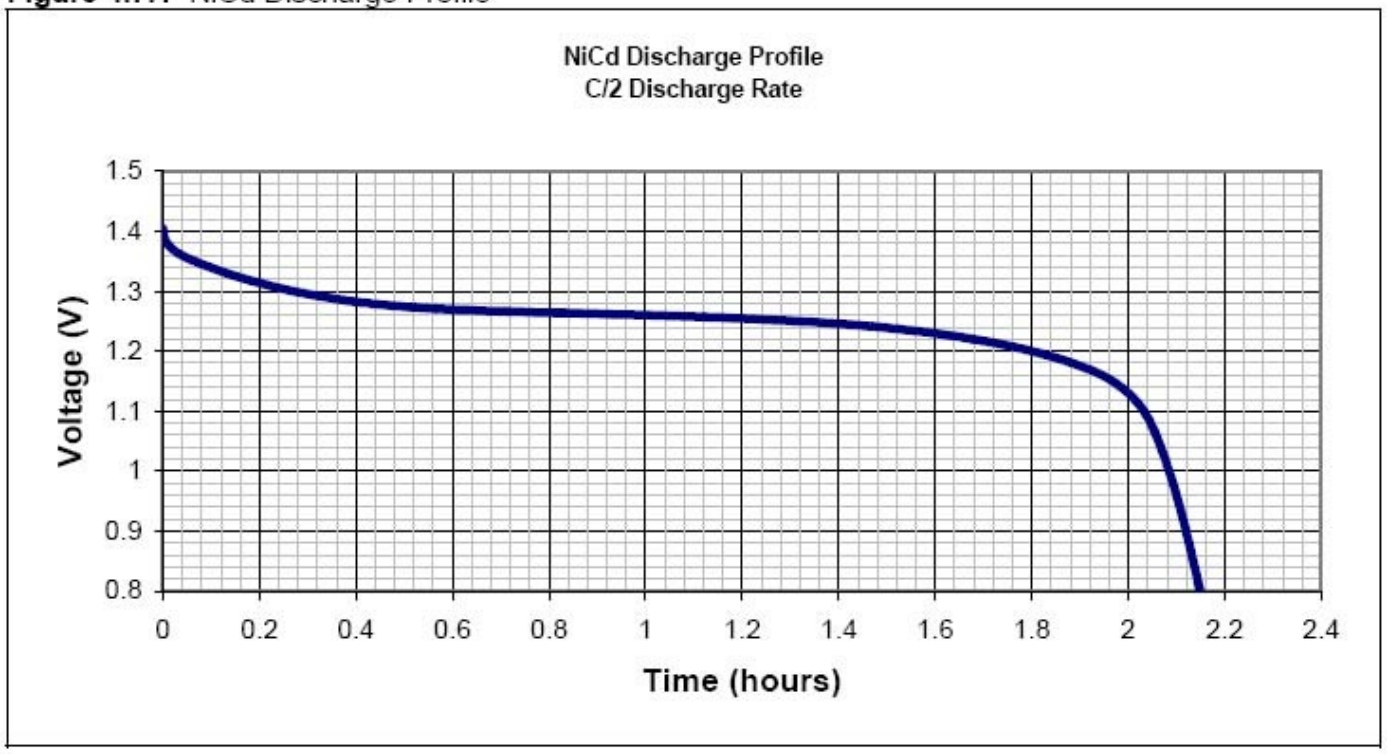


Figure 4.7.1 NiCd Discharge Profile



- Long cycle life
- Stable voltage until near the end
- High current because low internal resistance
- Average operating voltage is 1.2V
- Excellent reliability

AO-51 NiCd Batteries

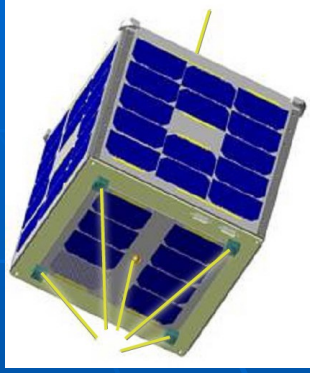
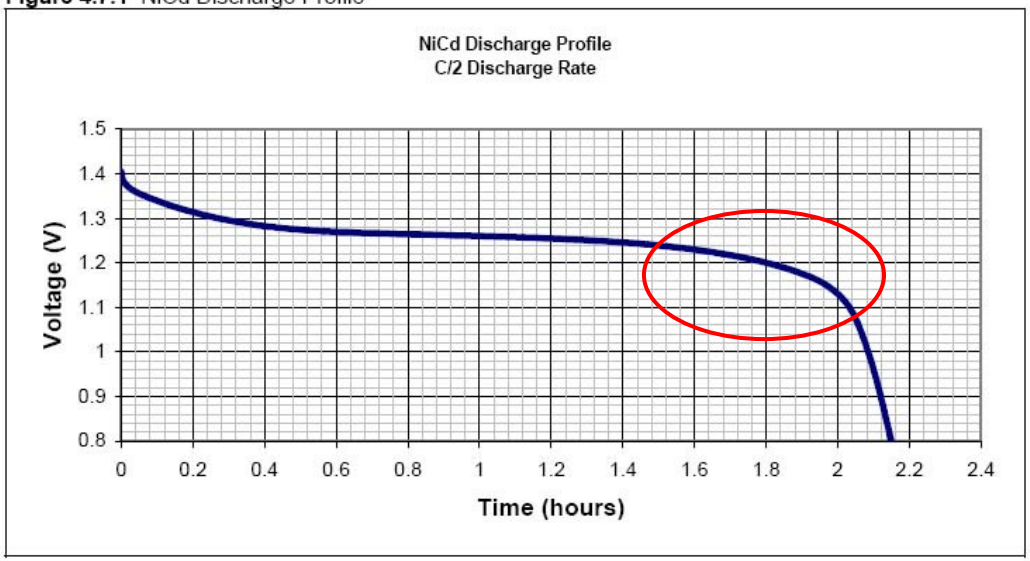
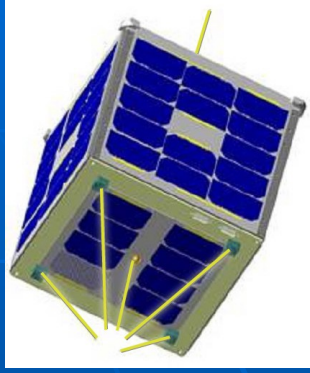


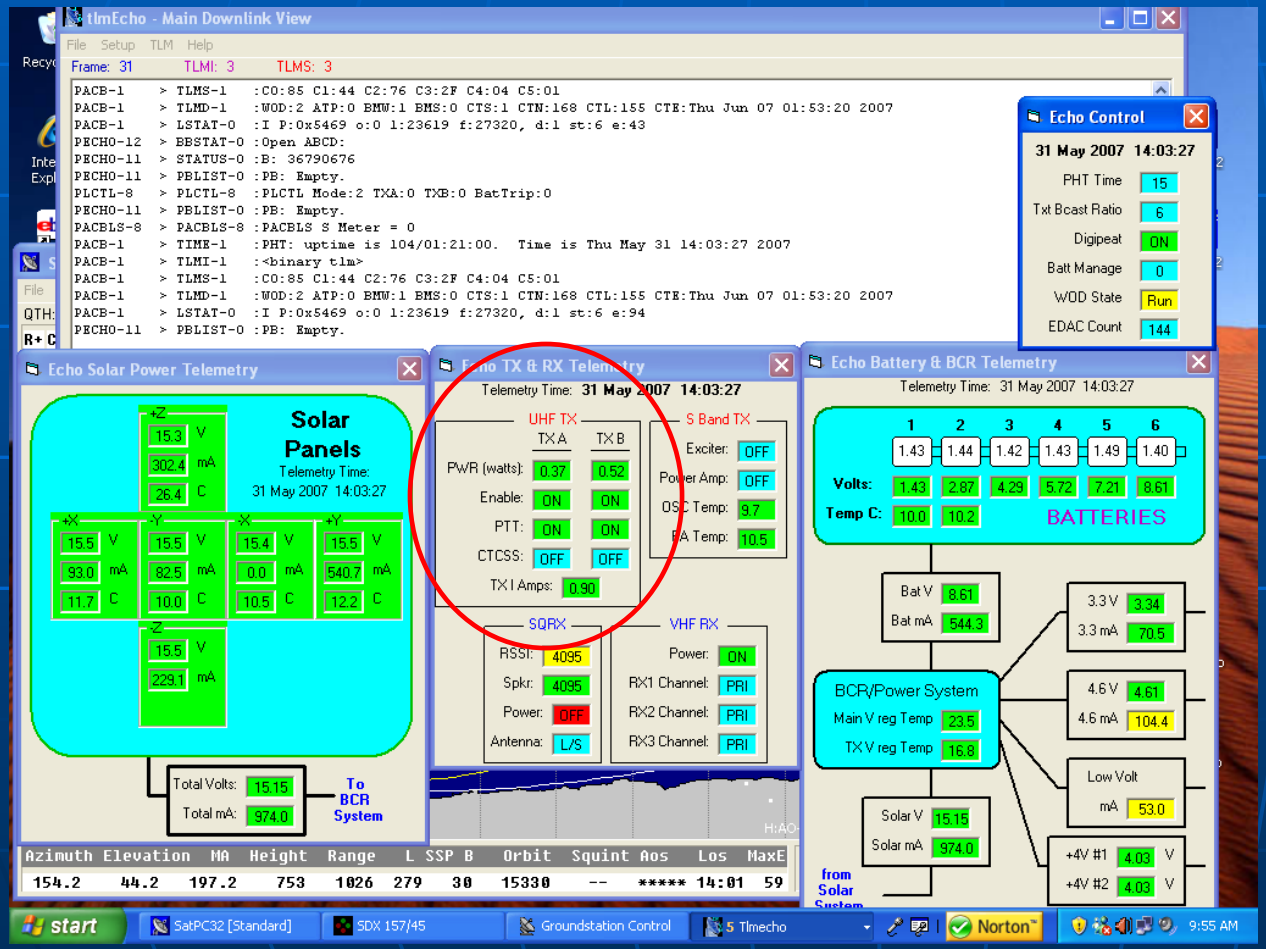
Figure 4.7.1 NiCd Discharge Profile



- These batteries do not completely discharge
- There are a number of theories on how much to discharge
  - We are currently using the 35-50% discharge model
  - Plus I am varying the low battery voltage point

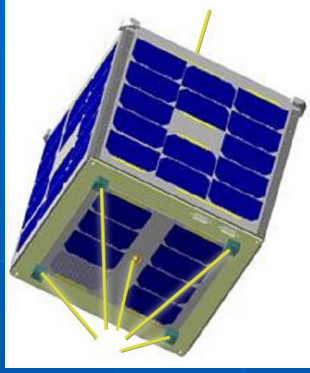
Setting AO-51 Minimum Battery Voltage

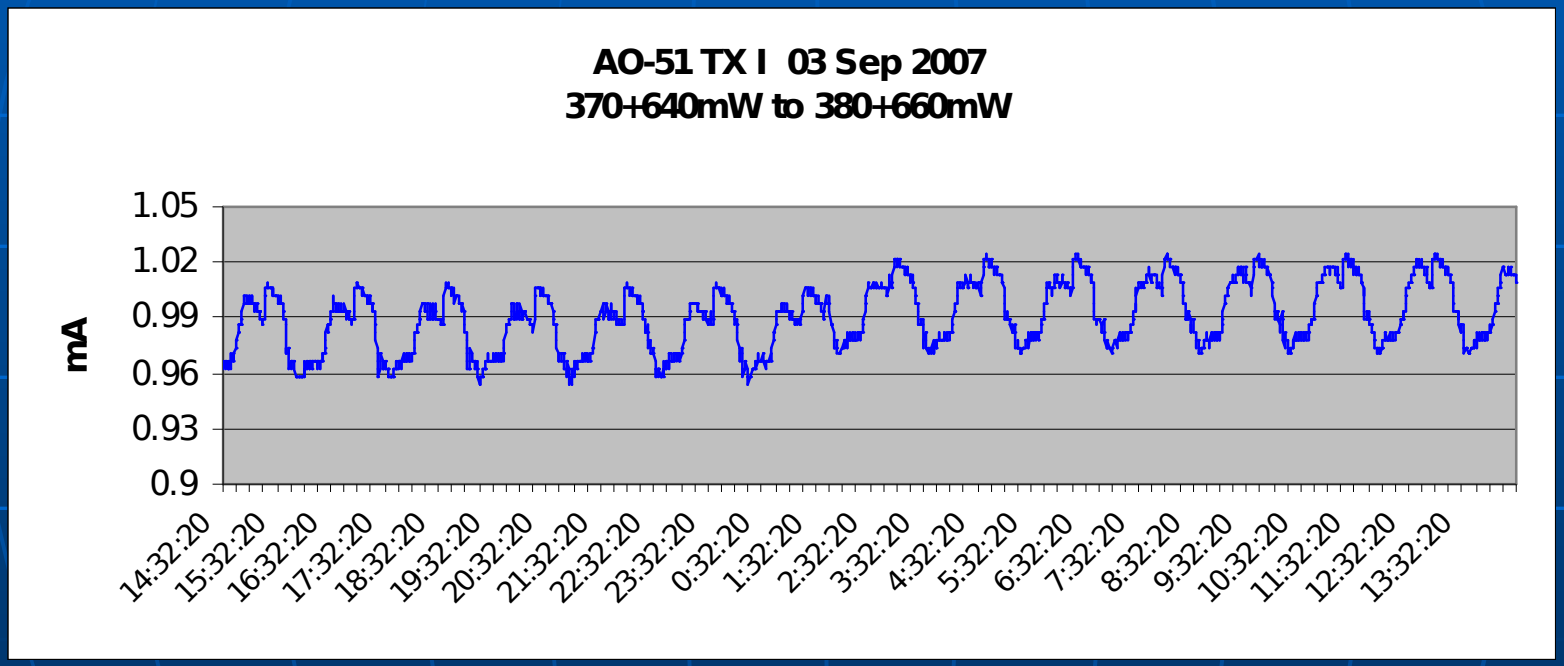




- The transmitters and any other modules (like SQRX) consume current at a fairly constant rate during eclipse
- I calculate how long the eclipse period is and how much power to run such that the batteries get close to the low voltage range.

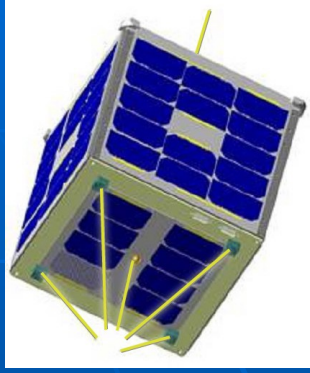
AO-51 TX Current Change

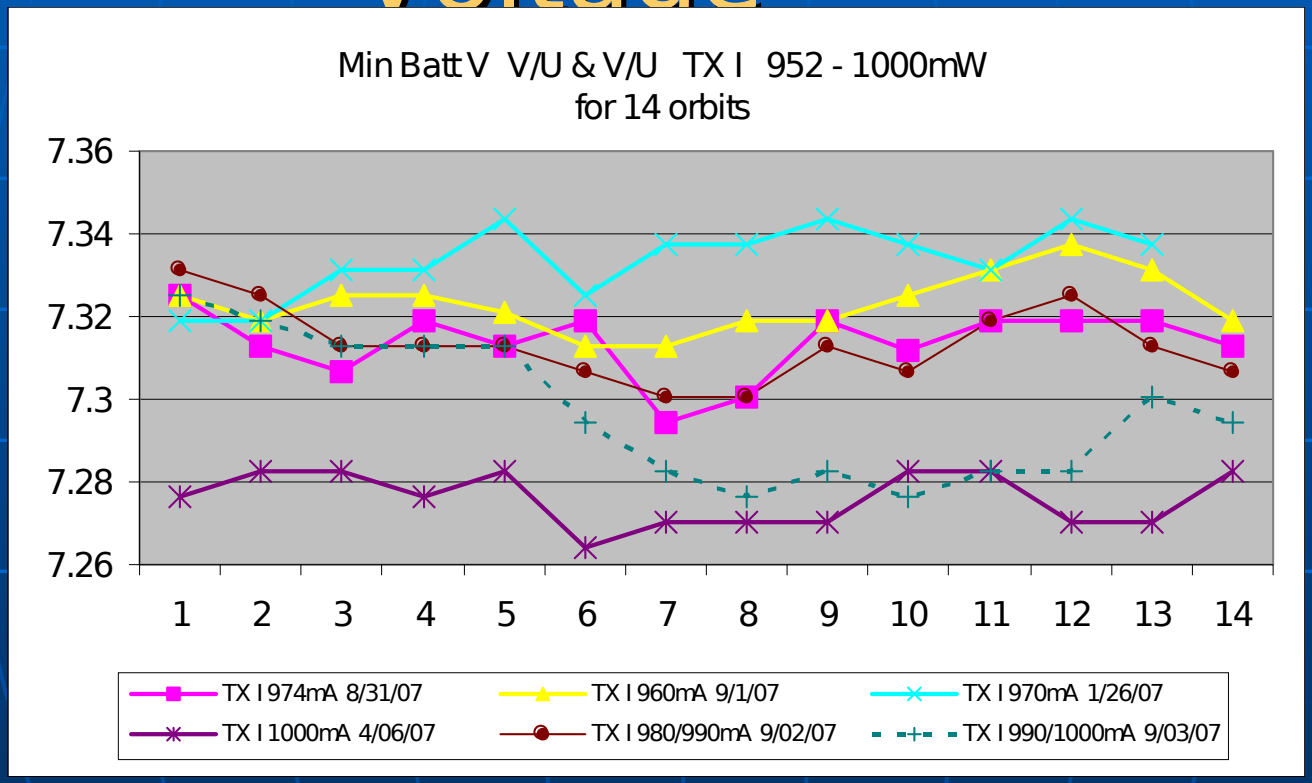




Around 02:32Z the UHF TXs output was increased from 1010mW to 1040 mW

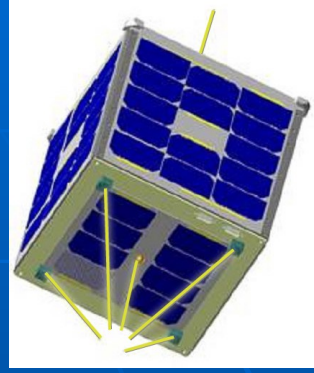
Effect of TX Power Change on Minimum Battery Voltage

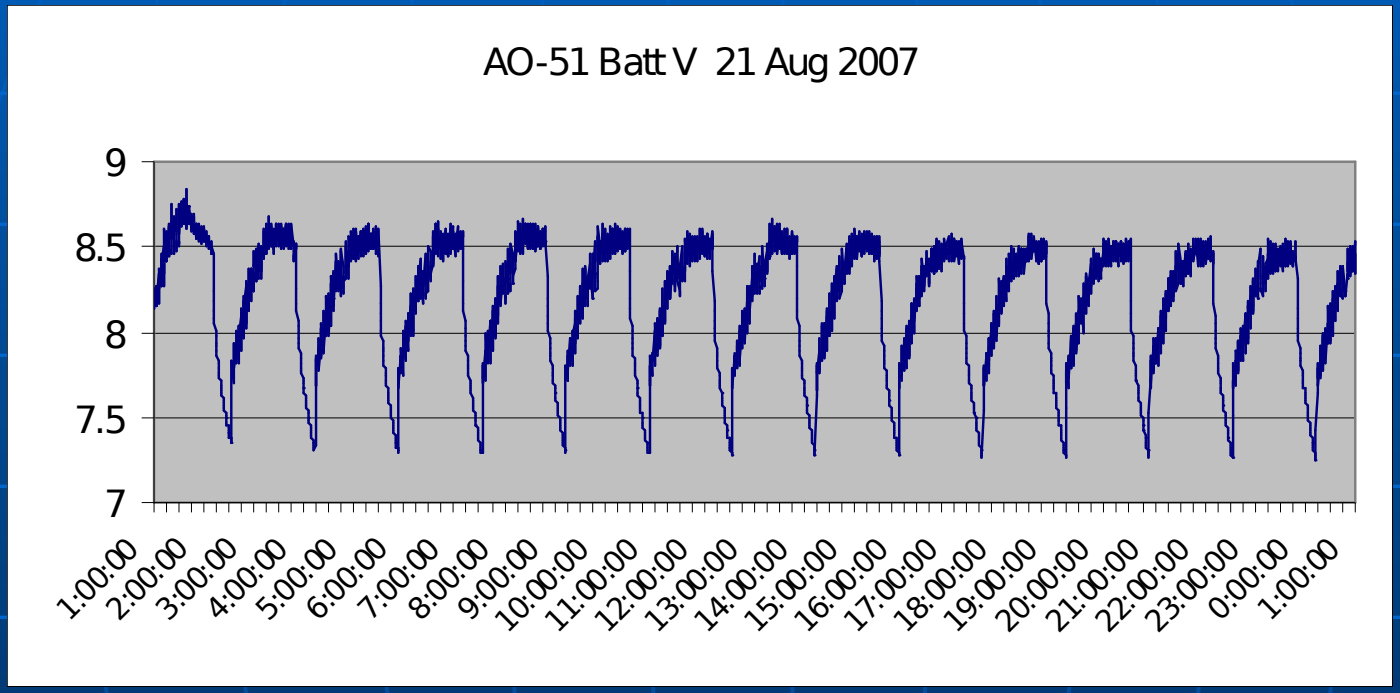




Minimum battery voltages for several orbits

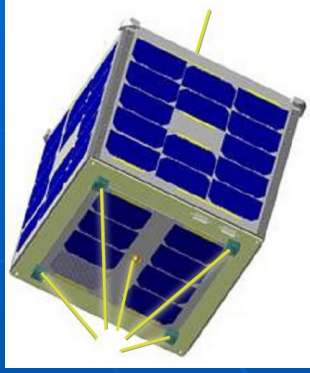
AO-51 21 Aug 2007 Data

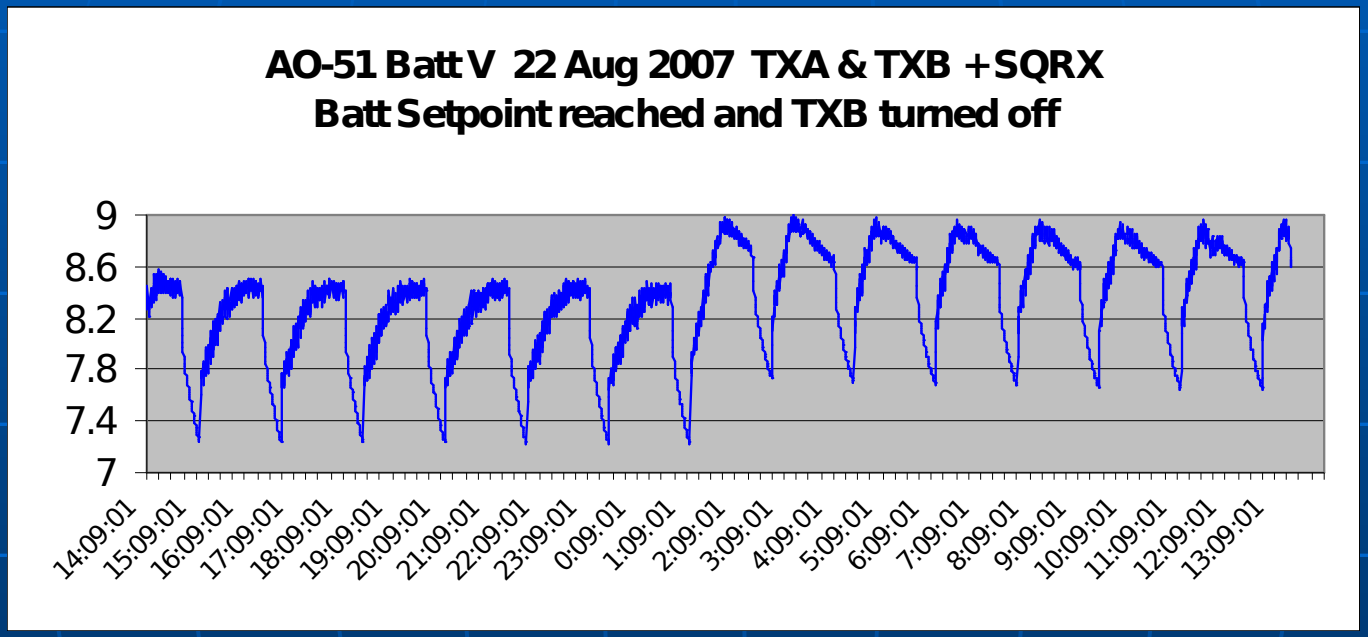




Satellite in V/U & L/U analog modes with SQRX on

AO-51 22 Aug 2007

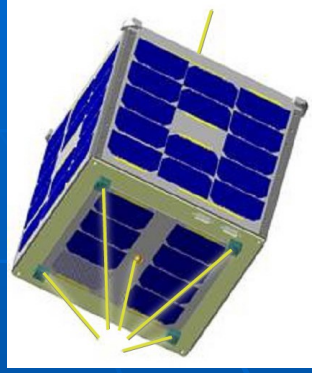


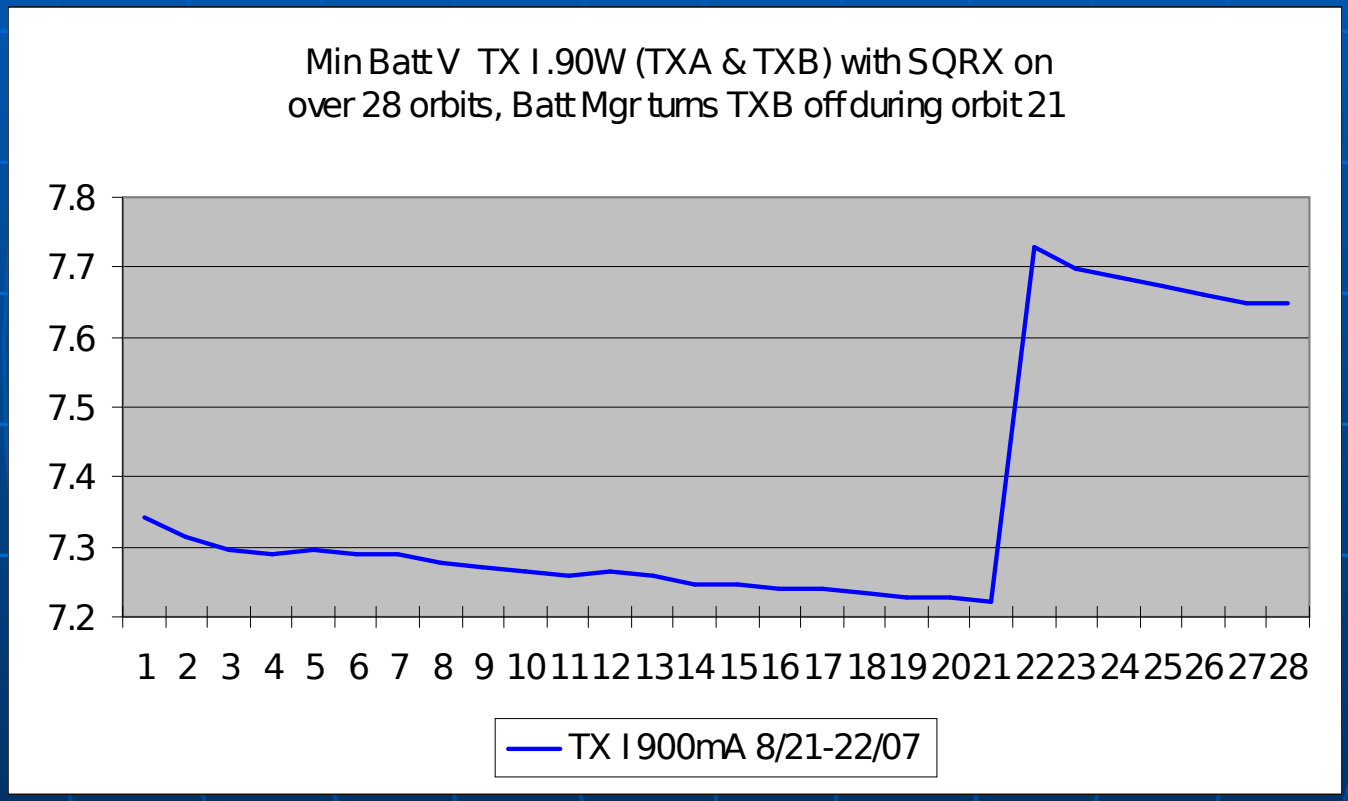


Satellite in V/U & L/U analog modes with SQRX on

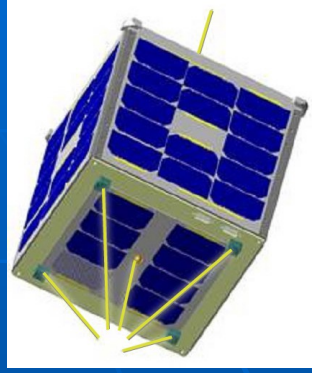
TX I changed from 910 mA to 430 mA

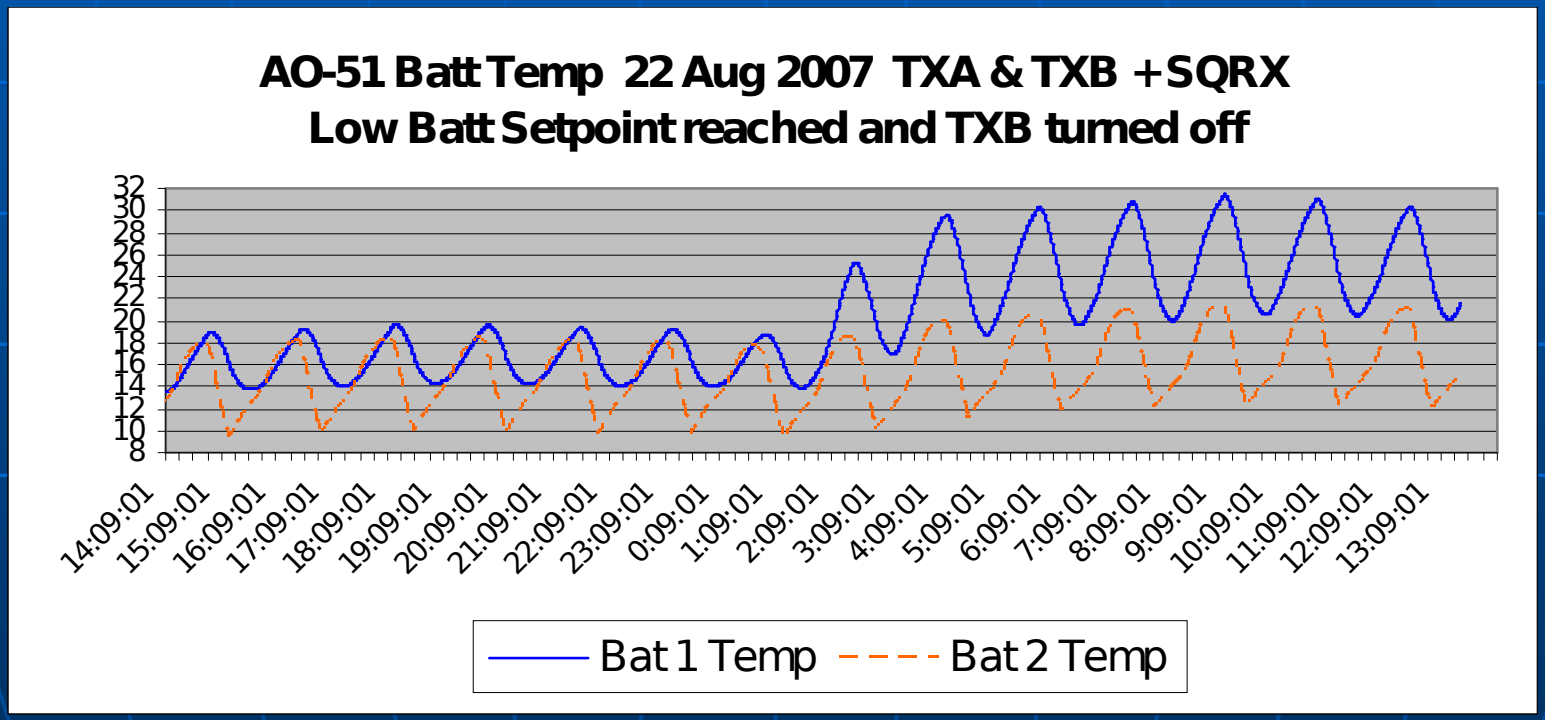
Minimum Battery Voltage Levels Leading up to 22 Aug Event



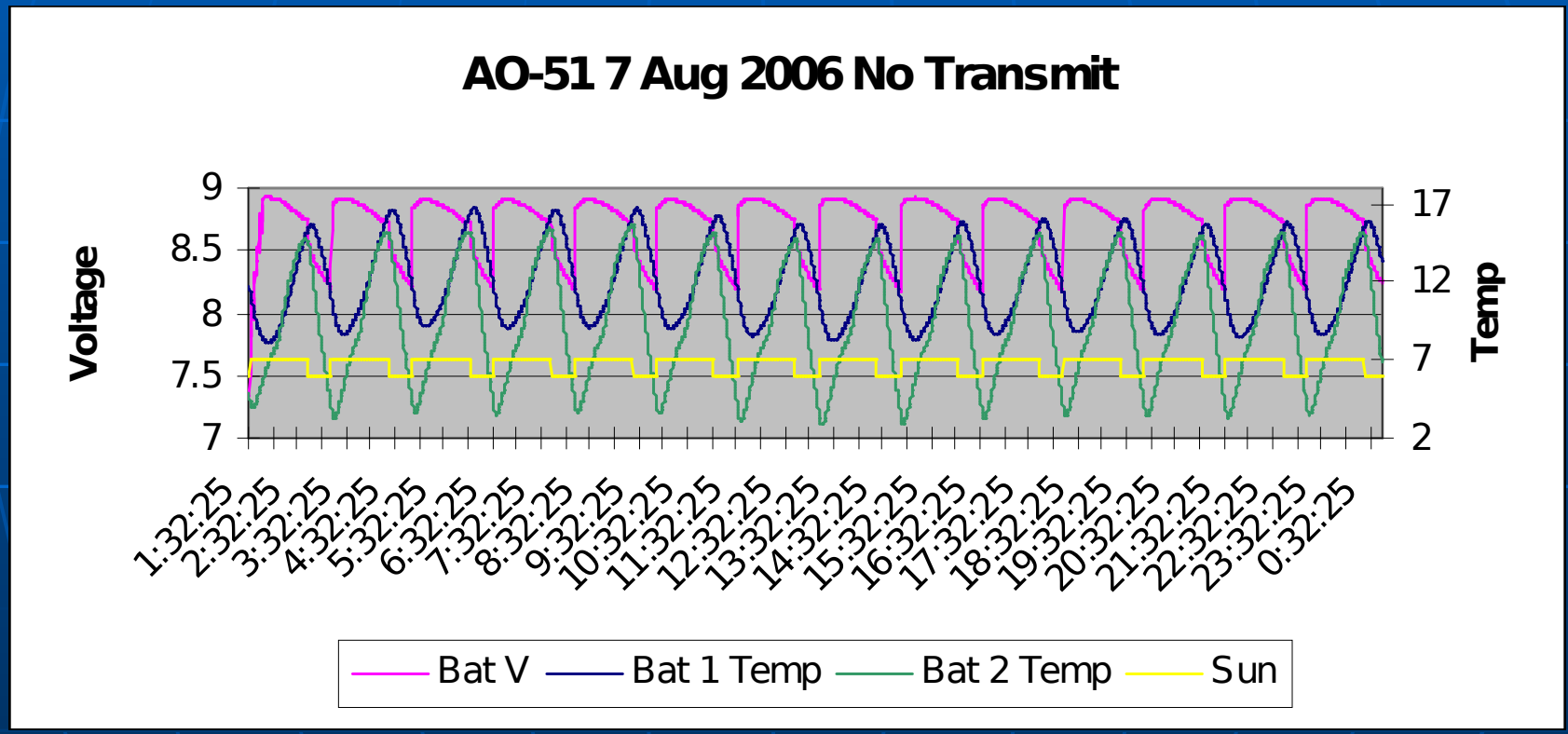


Effect on AO-51 Batteries During Low TX Power

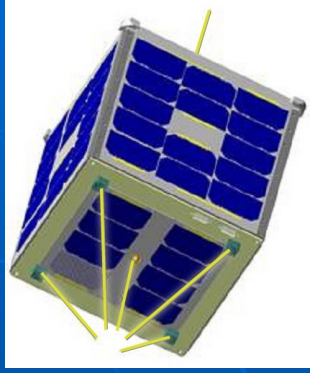


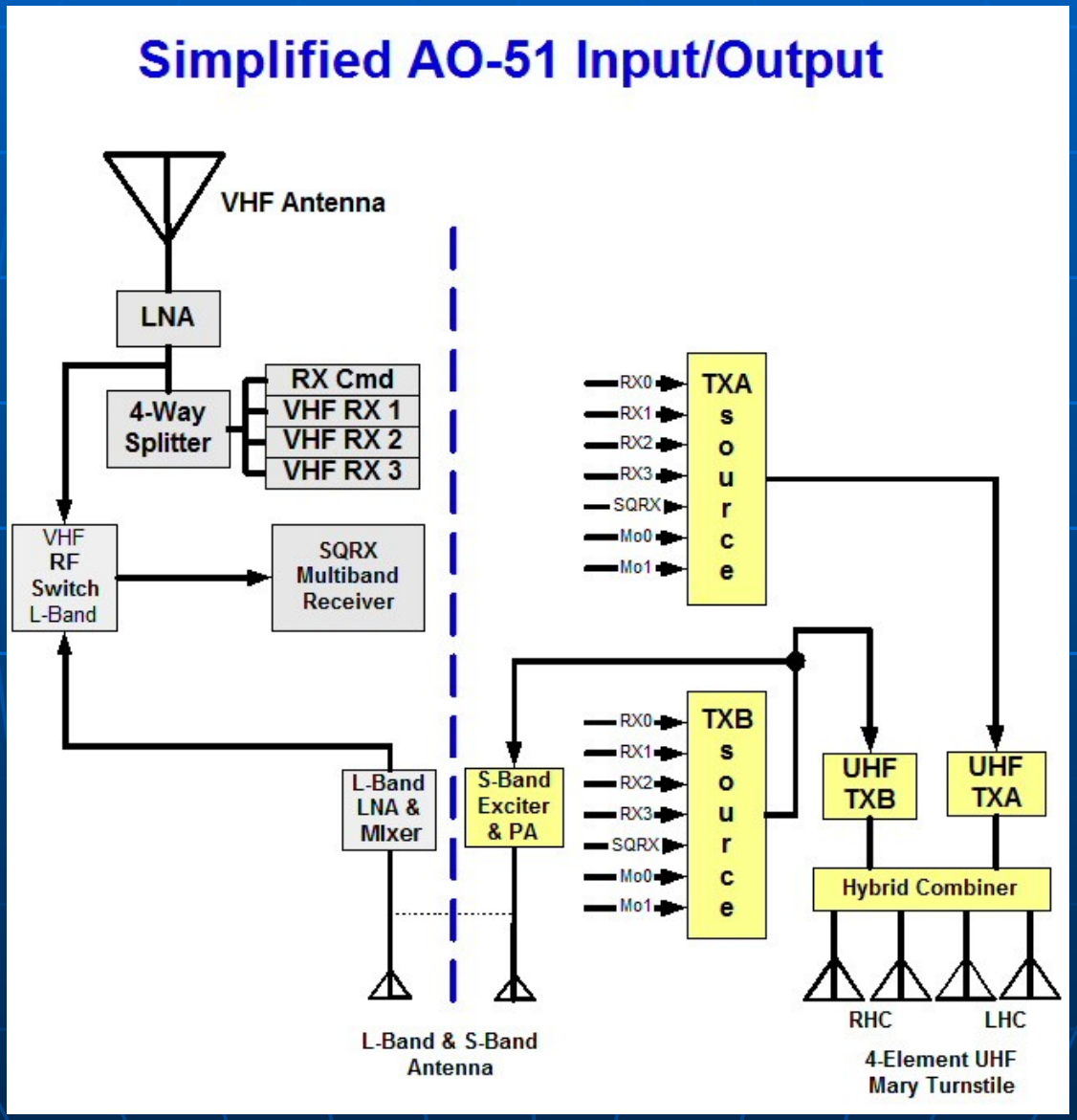


Effect on AO-51 Batteries During No TX Power

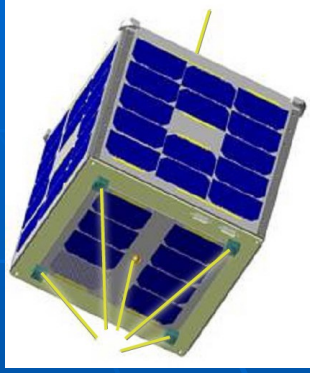


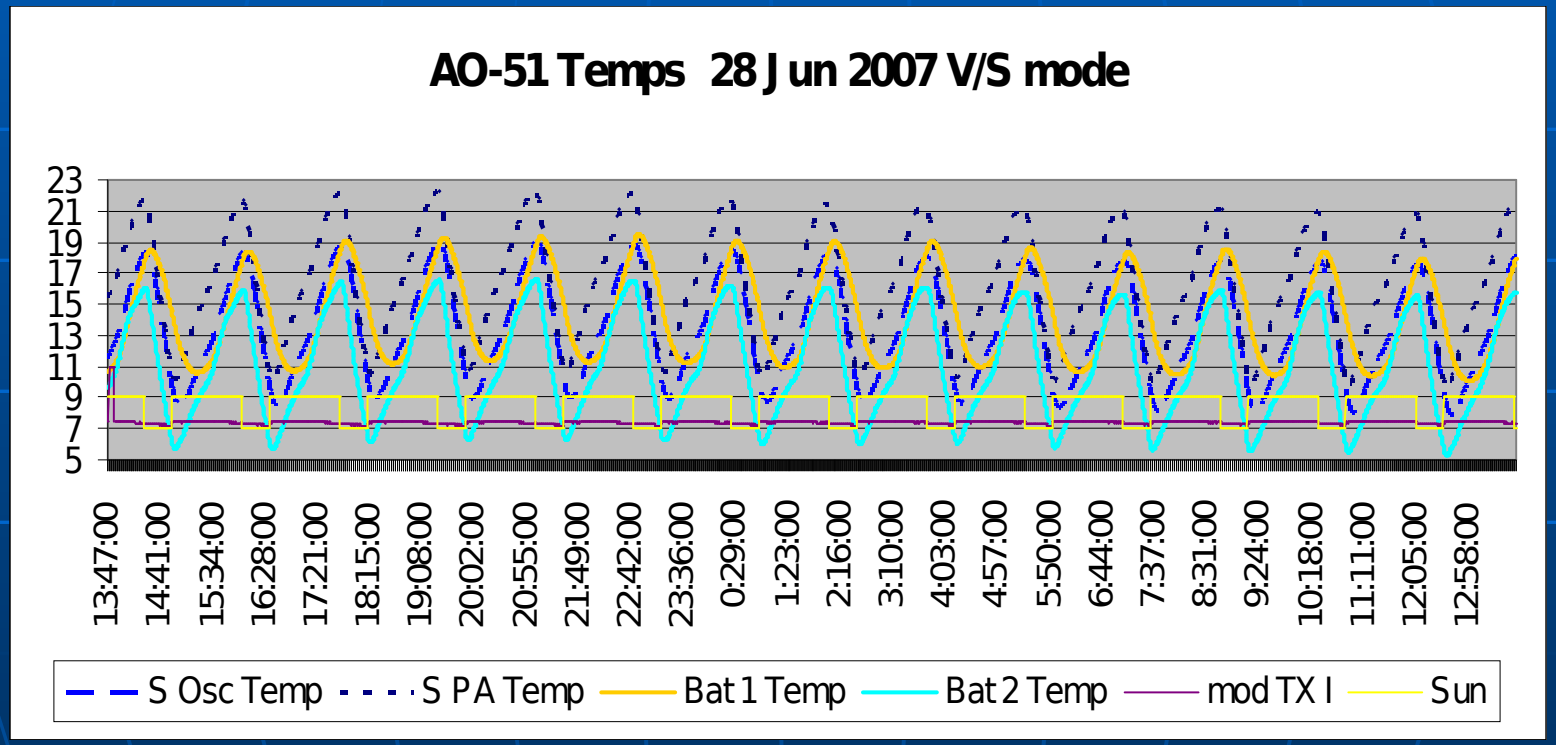
AO-51 RX/TX Matrix





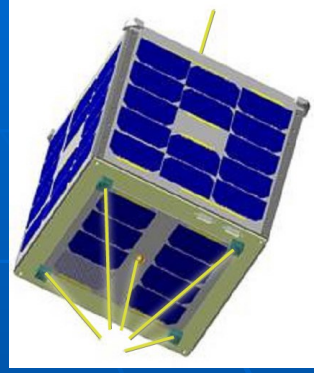
Battery Voltage and Temperature During V/S Mode

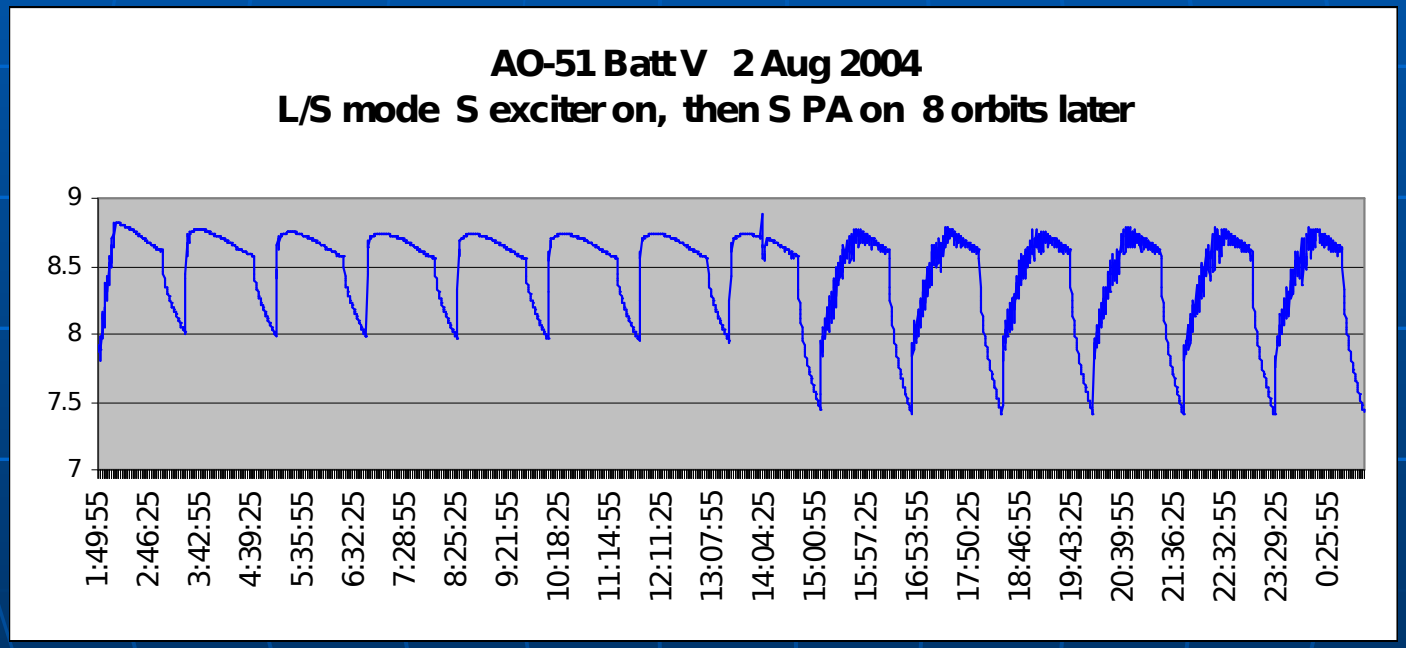




TX I is 745 mA consistently, low battery voltage avg 7.32V

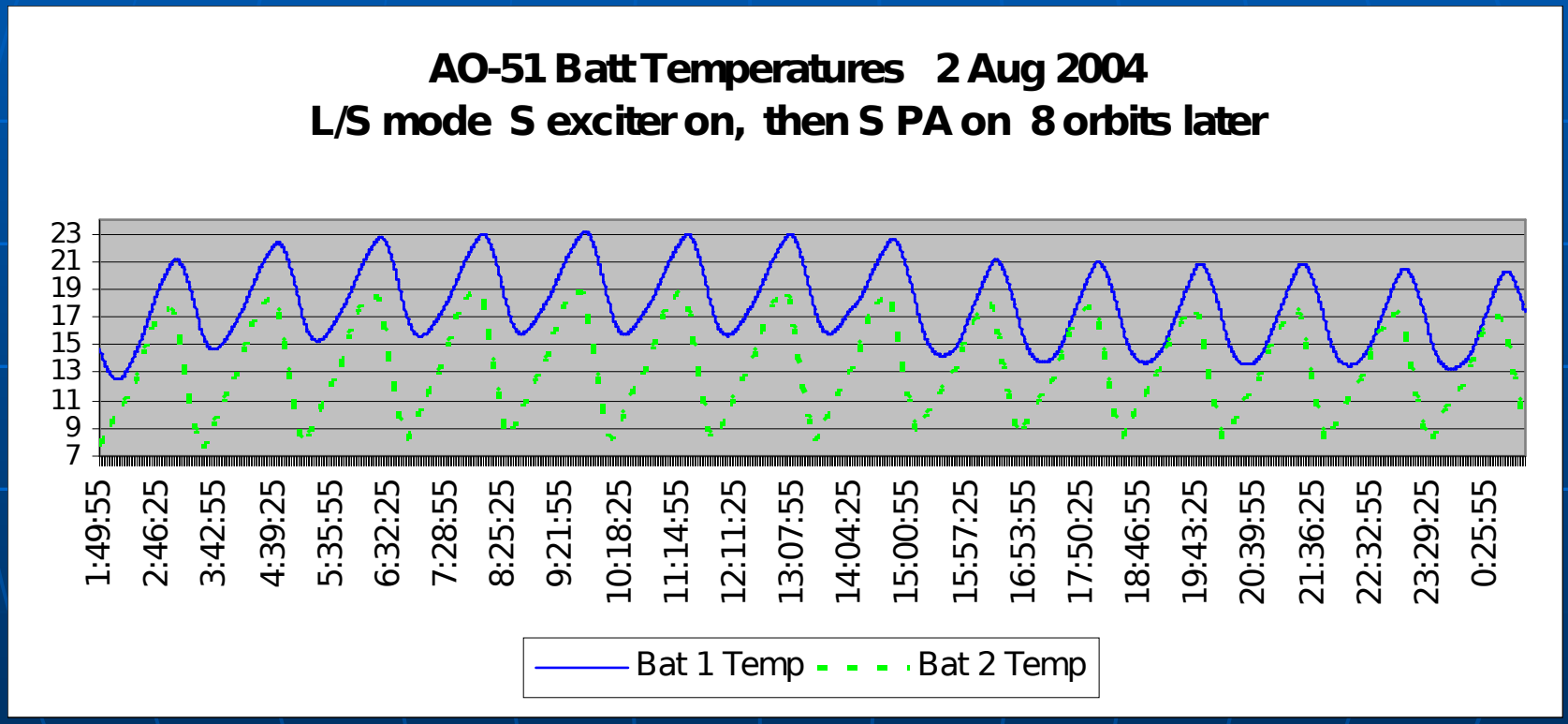
Battery Voltage at Very Low TX Power, Then Increase TX Power



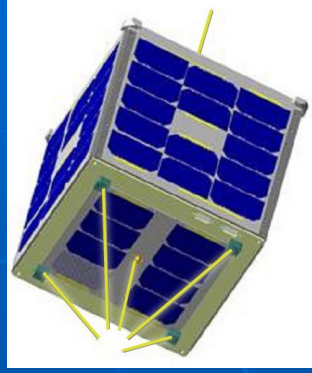


TX I is 25 mA & SQRX, low battery voltage avg 7.4V

Battery Temp at Very Low TX Power, Then High Power

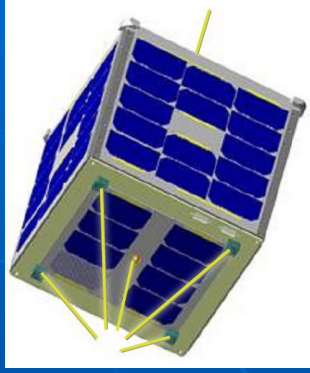


AO-51 Battery and Power Management



1. Optimize the output power levels to get through eclipse
2. Use as much power as possible to keep the battery temperature low
3. Monitor the current eclipse time
4. Develop configurable auto transmit power level control software

Future AO-51 Eclipse Periods



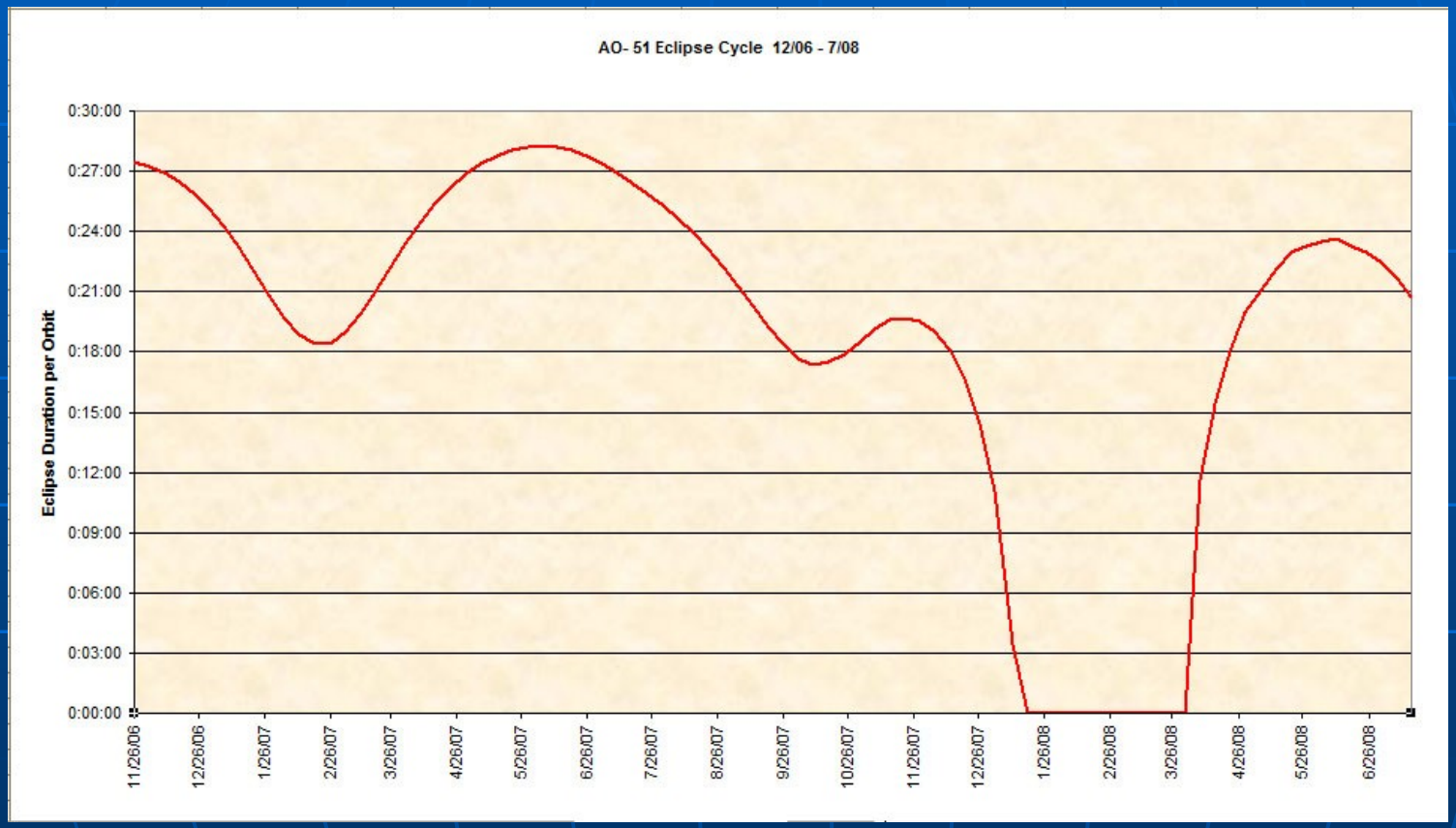
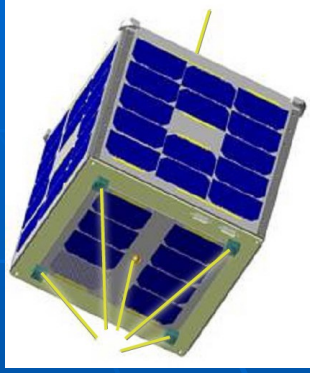


Chart by Colin, VK5HI using W4SM Eclipse Prediction software

Further AO-51 Eclipse Periods



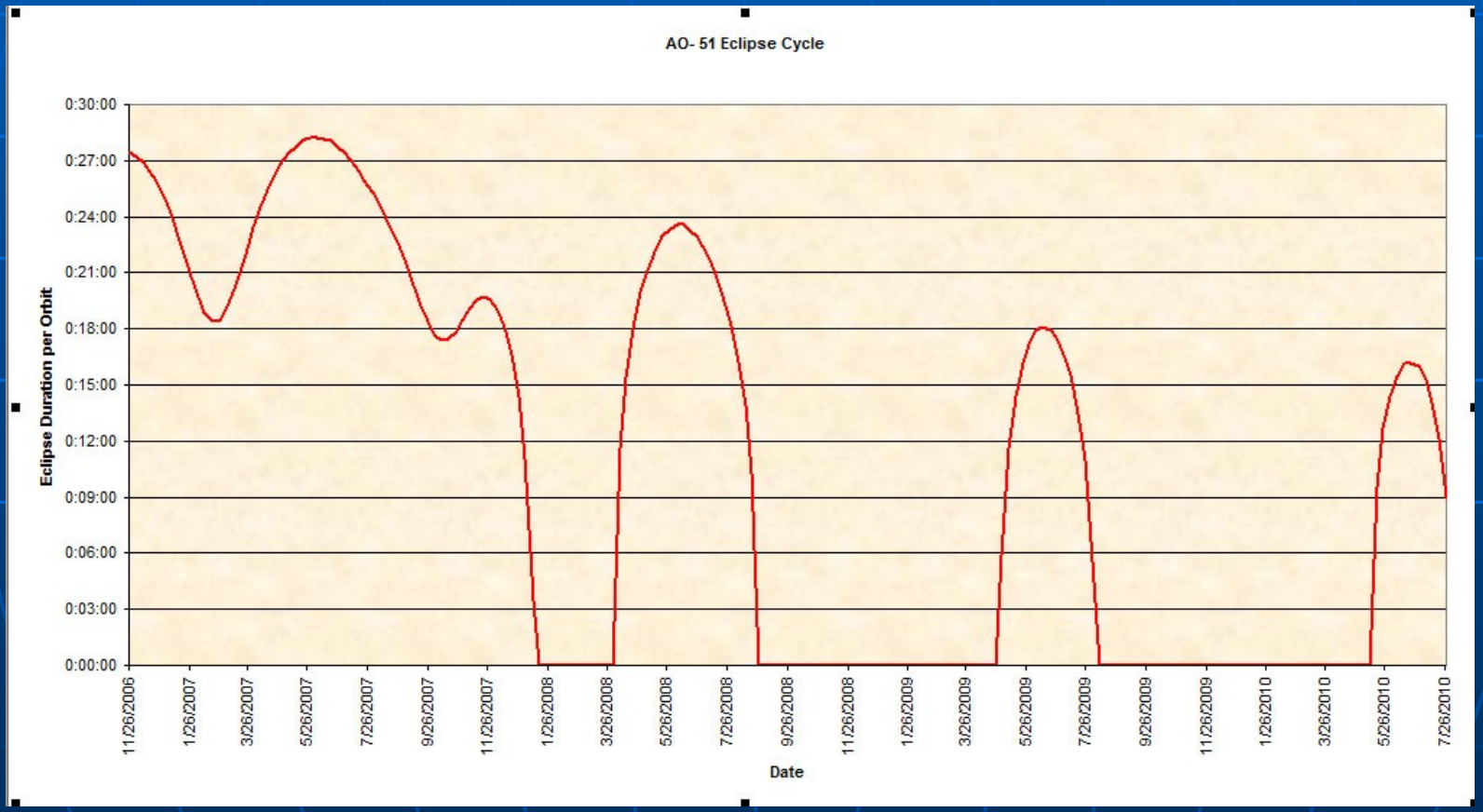
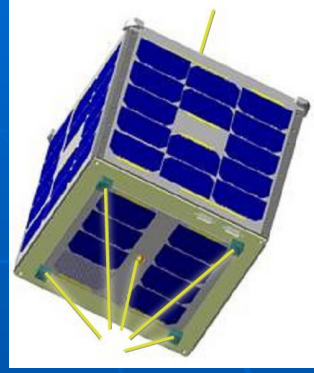


Chart by Colin, VK5HI using W4SM Eclipse Prediction software

AO-51 During No Eclipse

- We have talked with SpaceQuest many other experts
- Satellite expected to be able to handle this well
- Satellite will get a little warmer, but not to a worrisome level
- We will be transmitting to use energy

AO-51 Power System



Questions?